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RESEARCH ARTICLE

Highly disparate bird assemblages in sugarcane and pastures: implications for bird conservation in agricultural landscapes

Assembleias de aves altamente diferentes em pastagem e cana-de-açúcar: implicações para a conservação de aves em paisagens agrícolas

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Abstract

Sugarcane and cattle pastures are two of the most widespread and economically important agricultural landscapes. However, in Brazil, they have not been properly investigated for their importance to native birds and wildlife conservation. Thus, we aim to characterize and compare bird assemblages of

sugarcane and cattle pastures; and understand how landscape features within both habitats influence bird assemblages. We surveyed birds in both agricultural habitats over one year, and then investigated the relationship between species richness and composition with landscape diversity, matrix permeability, and the size and distribution of natural forests close to both habitats. We observed 132 species in cattle pastures and only 72 in sugarcane (48% bird community similarity). We further evaluated the richness and relative abundance of avian ecological groups, including habitat specialists and habitat generalists, insectivores, omnivores, granivores and frugivores. All avian groups were higher in pastures, the habitat where landscape heterogeneity and number of scattered trees was higher. Our results show that overall increasing landscape heterogeneity favors an assemblage with higher richness and composed by species with more diverse ecological functions. Therefore, we argue in favor of management practices that incorporate heterogeneity in agricultural landscapes, mainly in sugarcane fields where a homogeneous scheme has been used. Otherwise, the potential of agricultural landscapes for bird conservation will be highly hindered, particularly if the sugarcane sector expands to other agricultural lands.

Resumo

Cana-de-açúcar e pastagens para a pecuária são os dois usos de solo mais presentes em paisagens agrícolas e conferem uma elevada importância econômica ao país, porém, no Brasil ambas ainda foram pouco investigadas quanto à sua importância para a fauna nativa e sua conservação. Assim, objetivamos: (1) caracterizar e comparar as assembleias de aves ocorrentes em áreas de canaviais e pastagens; e (2) compreender quais características da paisagem dentro de cada um destes habitat agrícolas influenciam as assembleias de aves. Para isso, nós amostramos populações de aves em ambos os habitat por um ano e então analisamos a relação existente entre riqueza e composição das aves com a diversidade da paisagem, a permeabilidade da matriz agrícola, e o tamanho e distribuição dos fragmentos florestais próximos. No total, 132 espécies foram observadas em pastagens e 72 foram observadas nos canaviais (48% de similaridade entre as comunidades). Após, investigamos a riqueza e abundância relativa de diferentes grupos funcionais de aves, incluindo espécies especialistas e generalistas de habitats, espécies insetívoras, onívoras, granívoras e frugívoras. Todos estes grupos apresentaram maior riqueza e abundância nas áreas de pastagens, habitat que apresentou maior heterogeneidade da paisagem e número de árvores isoladas. Embora alguns grupos funcionais não tenham apresentado relações contundentes com as variáveis da paisagem, nossos resultados mostraram que, de maneira geral, o aumento da heterogeneidade na paisagem favorece a ocorrência de uma assembleia mais rica e composta por espécies com grande variedade de funções ecológicas. Portanto, encorajamos que práticas de manejo que favoreçam uma maior heterogeneidade sejam adotadas nas paisagens agrícolas, principalmente no caso das áreas de cana-de-açúcar, aonde uma esquematização de paisagem homogênea tem sido utilizada. Caso contrário, o potencial das paisagens agrícolas para a conservação de aves será bastante prejudicado, principalmente num futuro próximo, já que o setor canavieiro pretende se expandir devido à demanda global por biocombustíveis.

Keywords

Agricultural impacts, biofuel, dairy production, land sharing, land sparing, scattered trees, sugarcane expansion

Palavra-chave

Biocombustíveis, compartilhamento de terras, conservação na agricultura, expansão canavieira, impactos da agricultura, ornitologia, pecuária, poupança de terras

Introduction

Croplands cover around 12% of the world's terrestrial area (Gong et al. 2013). Each crop requires different management practices and natural resources, which consequently influence the agricultural landscape characteristics (Fahrig et al. 2011; Verdade et al. 2016). The tradeoff between the decisions for land use follows local and global economic tendencies (Lambin and Meyfroidt 2010). Although impacts on societies and economies are the main concern for policy-makers (e.g., Martinelli and Filoso 2008; Novo et al. 2010; Egeskog et al. 2011; Barretto et al. 2013), land use also affects the biodiversity of agricultural landscapes (Verdade et al. 2014).

Because of the variety of ecological functions performed by birds, they are considered a good indicator of overall biodiversity in agricultural landscapes (Sekercioglu et al. 2016; Alexandrino et al. 2017). Understanding which species use different crops and which species have the ability to disperse across crops (e.g., some forest species, Biz et al. 2017) is useful for providing guidelines for designing agricultural landscapes that are biodiversity-friendly (Verdade et al. 2014). Shade coffee in Central America (Petit et al. 1999; Petit and Petit 2003; Tejeda-Cruz and Sutherland 2004; Leyequién et al. 2010) and Ethiopia (Buechley et al. 2015) are examples of particularly important crops for biodiversity.

Although birds have been surveyed in various agricultural crops worldwide (e.g., Bennett et al. 2006; Fischer et al. 2008; Fahrig et al. 2011), Brazilian crops have been little-studied in this regard, despite Brazil's global importance for both agriculture and biodiversity. As a result, data on species occurrence and crop usage is scarce. Sugarcane and cattle pastures are the two most abundant crops in southeastern Brazil (IBGE 2018; UNICA 2018), yet there are only a few published peer-reviewed works investigating birdlife in these crops, such as in pastures (Machado and Rosa 2005; Pizo and Santos 2011; Silva et al. 2015), in sugarcane (Miranda 2006; Miranda and Avellar 2008) as well as in both crops (Penteado et al. 2016). These crops have been present in southeastern Brazil for more than 50 years (e.g., Ferraz et al. 2014), and each one has different characteristics and production dynamics, which are likely to influence bird communities.

Sugarcane was introduced to Brazil from India in the 16th century to help meet sugar demand in Europe (Vian et al. 2015). In 1930, Brazil initiated ethanol production from sugarcane. During the 1970´s, the Brazilian government made ethanol addition in automobile fuels mandatory (i.e., the Proálcool program) and began subsidizing sugarcane production, which led to an expansion of the crop (Soccol et al. 2005; Gauder et al. 2011). Although a reduction in ethanol production occurred in the early 1990´s (because the end of Proálcool program, see Soccol et al. 2005), in the early 21st century global demand for biofuels boosted again the expansion of sugarcane (Martinelli and Filoso 2008; Bernard et al. 2011). Currently, Brazil is the world leader in sugarcane production and about 50% of Brazilian production is from the southeast of the country (IBGE 2018; UNICA 2018). The crop produc-

tion cycle is short. In general, eight months after planting, sugarcane is ready to be harvested (Aguiar et al. 2011). Most sugarcane fields are planted in flat terrain, for optimization of mechanized harvesting (Margarido and Santos 2015). Crop rotation is rarely done (e.g., Bolonhezi and Gonçalves 2015), which leads to a homogeneous aspect in the landscape. Furthermore, high yield sugarcane fields are usually located near processing plants (Vian et al. 2015), because they require a constant supply of raw material in order to maintain the monetary value of the final product (i.e., ethanol and sugar) (Margarido and Santos 2015). With a large crop area in private properties (or in many small leased farm fields next to each other), plants are obligated by the Brazilian Forest Code (Brazil 2012) to maintain native forest (i.e., legal reserve) in their lands, which are usually isolated patches in the landscape (e.g., Ferraz et al. 2014; Alexandrino et al. 2017).

In comparison, Brazilian cattle pasture fields are composed of tropical grasses (e.g., signal grass - *Urochloa decumbens*, elephant grass - *Cenchrus purpureus*and Guinea grass - *Megathyrsus maximus*) used for beef and dairy cattle forage. Cattle ranching has occurred in Brazil since the 16th century (see Dean 1997), and has been a rural way of subsistence and income passed down through generations. Contrary to sugarcane, cattle pastures may be established in topographically rough terrain, as livestock can graze there. Furthermore, the grazing distribution over the territory does not follow the same commercial and geographical tendency observed in sugarcane production (i.e., large fields next to a processing center). Although nowadays cattle pastures are abundant in many agricultural landscapes in Brazil (i.e., this is the second most abundant crop in state of São Paulo, southeast Brazil, see São Paulo 2008; IBGE 2018), they are also present in many small family farms (Comin and Gheler-Costa 2016) that primarily raise cattle for local beef and dairy production. In these farms, orchards, vegetables and fruits are also cultivated at a small scale for subsistence and local markets (São Paulo 2008; e.g., Comin and Gheler-Costa 2016). In addition, pastures have low management intensity and low dependency of agrochemicals when compared to sugarcane, which allows the growth of shrubs and sparse trees in pasture fields. In many cases, these trees are intentionally maintained by cattle breeders to promote animal welfare from shade. Depending on the size of the farm, and whether there is a watercourse, the owner needs to keep some native forest, following the Brazilian Forest Code (Brazil 2012). All these aspects of cattle ranching lead to generally higher landscape heterogeneity within this crop type. Sugarcane has replaced cattle pastures and other crops recently in southeast Brazil (Rudorff et al. 2010; Lourenzani and Caldas 2014), a tendency likely to continue due to Brazil's high ethanol production goals (Vian et al. 2015).

Recent research in this region has shown that there is a similar bird species composition in small forest reserves that are located within sugarcane and cattle pastures matrices (Alexandrino et al. 2016, 2017). This led us to focus on comparing bird communities within both of these crop types. Ultimately, this information is helpful in the planning of agricultural landscapes that can be beneficial to society (i.e., providing food and raw material) and biodiversity conservation (see land sparing vs. land shar-

ing debate, Fischer et al. 2008, 2011; Phalan et al. 2011, 2016). Specifically, given the differences between sugarcane and cattle pastures and the lack of knowledge about bird communities occurring in both crops, in this paper we aim to: (1) characterize and compare bird assemblages in sugarcane fields and cattle pastures; and (2) understand which landscape features of both crops influence bird assemblages.

Material and methods

Study area

Our study was carried out in the Corumbataí River Basin, in the state of São Paulo, southeastern Brazil (22°04'46"/ 22°41'28"S and 47°26'23"/ 47°56'15"W) (Fig. 1A). With 1710 km^2, this river basin is mainly composed of cattle pastures (occupying 44% of the river basin, mostly in the north) and sugarcane fields (occupying 26% of the river basin, mostly in the south). These two distinct matrices each have been present for more than 40 years in the agricultural landscapes of this region (Ferraz et al. 2014). Native forest (semi-deciduous Atlantic Forest) and savannah woodlands (*Cerrado* biome) that originally covered this river basin are still present in small forest patches (Fig. 1B). There are also other crops in small portions, as well as urbanized zones (Valente and Vettorazzi 2003). The topography is moderately hilly (Garcia et al. 2006), and the climate is subtropical (i.e., Cwa climate on Köppen classification, see Alvares et al. 2013), with a rainy (October – February) and dry (March – September) season.

Sugarcane in the southern river basin is destined for ethanol and sugar production in nearby plants (UNICA 2018; Vian et al. 2015). Pastures in the northern basin are mainly in small family farms (Comin and Gheler-Costa 2016), which make the pasture fields smaller than in other parts of southeast Brazil, where cattle ranching with high yields predominates (e.g., in Corumbataí municipality, northern river basin, pastures of *Urochloa* grass fill 91.7 km^2, while in Mirante do Paranapanema municipality, in the extreme west of the state of São Paulo, there is a total of 915 km^2 of *Urochloa* grass, see São Paulo 2008; Novo et al. 2010).

Sampling design

Our fieldwork was performed in five focal landscapes, which have been used in previous studies (Ferraz et al. 2014; Alexandrino et al. 2016, 2017) (Fig. 1B). Each one was 16 km^2 and composed of 70% sugarcane or pasture matrix and at least 10% native forest. Therefore, they roughly represent the general agricultural landscape in this region. Further details about the allocation procedure of each focal landscape can be found in Ferraz et al. (2014).

We selected four bird survey plots in sugarcane plantations from the focal landscapes in the south and four in pastures from the focal landscapes in the north (Fig. 1C). Using a 2008 land-use map (using ArcGIS 9.0) all bird survey plots were allocated to the interior of the crop, at least 350 meters from any other land use

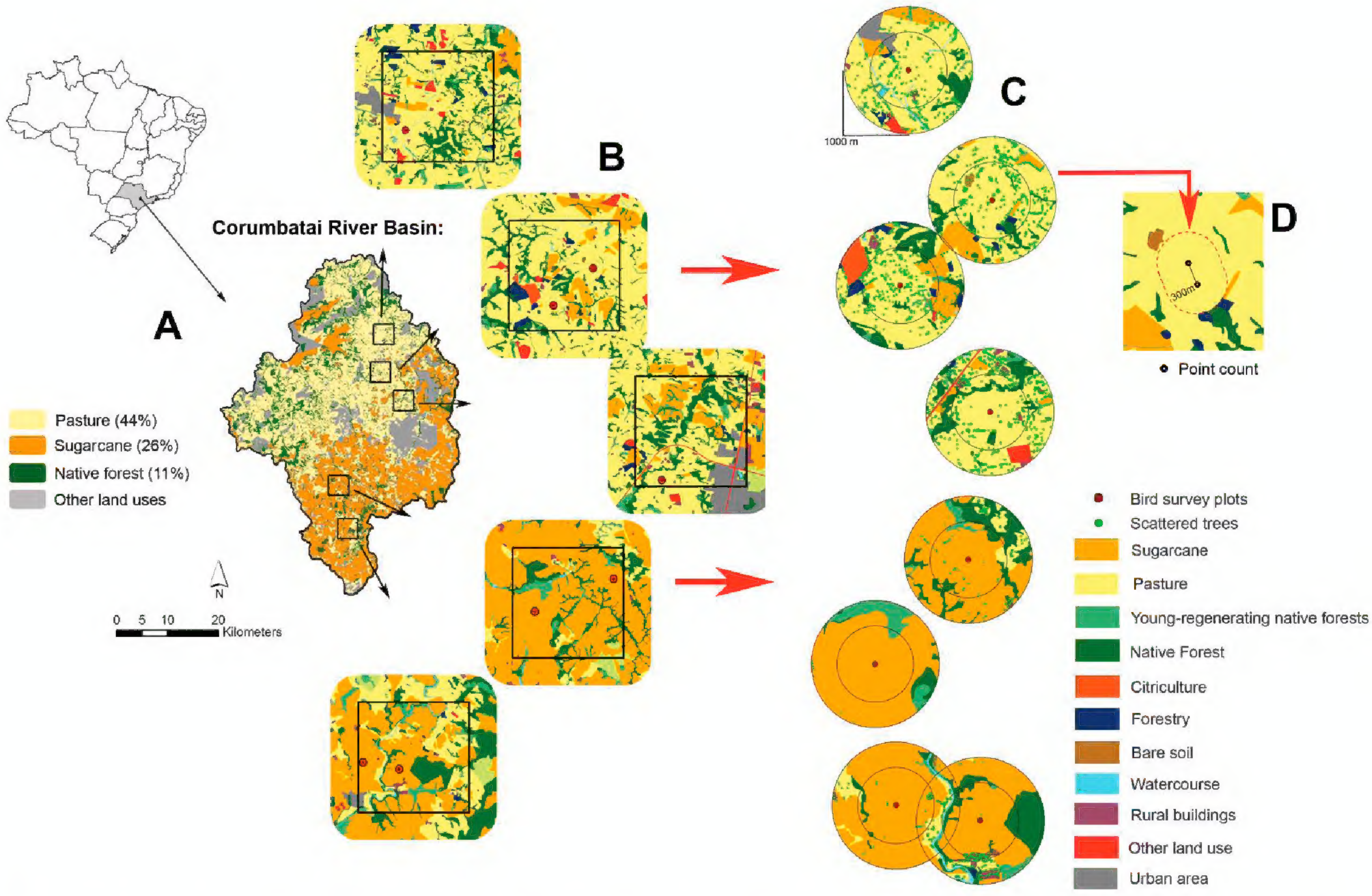

Figure 1. (A) Location of the Corumbatai River Basin in the state of São Paulo, southeastern Brazil. The river basin figure shows the main land use types (Valente and Vettorazzi 2003) and the five focal landscapes 16 km^2 (Ferraz et al. 2014) where our bird survey plots were allocated. (B) Focal landscapes are highlighted (squares) with the detailed land use type. Red points indicate the eight bird survey plots. (C) Concentric buffers with 1000 meters and 600 meters radii from each bird survey plot where the landscape structures were collected. (D) Details of bird survey plot and the area used for bird sampling. Each one was composed by two point counts and one line transect. From top to bottom the name of each bird survey plot is: P1, P2B, P2A, P3, SC1C, SC1B, SC2D, SC2E. Names stated with SC means sugarcane matrix and P means pasture matrix.

type. This was the largest common distance observed between the studied crops and the other land uses type in all focal landscapes (Alexandrino 2015). Additionally, because of temporal variability in the sugarcane height throughout the growing season, since it can reach up to 3 m high, thus limiting visibility, we used only dirt roads that cross the sugarcane fields to allocate our bird survey plots. This procedure allowed a constant minimum panoramic area search during the whole period of survey. Because the harvesting sugarcane (e.g., slash and burn, mechanized) may influence fauna assemblages inside the crop (e.g., Gheler-Costa et al. 2013), we selected sugarcane fields that used mechanized harvesting methods during the whole survey period.

Bird surveys

We sampled birds at survey plots, which were composed of two point counts located 200 m from each other and a line transect between them (Fig. 1D). Point counts

were used for bird relative abundance (i.e., obtained for each species), based on the Punctual Abundance Index (i.e., PAI = accumulated contact number at the bird survey plot/12 visits) (Vielliard et al. 2010). This abundance measurement method has been successfully applied in bird counts in varieties of habitats under heavy anthropogenic influence, including agricultural landscapes (e.g., Anjos 2004; Uezu et al. 2008; Alexandrino et al. 2017). Each point count lasted 10 minutes. Line transects were used to complement the bird species list of each bird survey plot while the observer moved from one point to another. Each bird survey plot was visited 12 times, once per month from November 2011 to November 2012. The sampling period was between sunrise and 11 am and field work was not conducted during rain. In each visit, each point count and line transect was sampled once. We recorded species visually or aurally detected within 300 m of the line transect or point count and we excluded flyovers (i.e., birds that flew high altitudes over the plot without landing there, e.g., Silva et al. 2015; Penteado et al. 2016) (Fig. 1D). This sample buffer was delimited in the field before the beginning of the bird surveys, and it was used to avoid recording species in other land use types nearby.

Landscape structures

Landscape structure was derived from a 2008 high resolution land use map composed of 13 land use classes and covering 35 km^2, which included each focal landscape (see Fig. 1). A description of each land use class is available in Table 1, and detailed methods for how the map was constructed is available in Suppl. material 1A.

Bird community composition and abundance in agricultural landscapes has been shown to be dependent on environmental features nearby (e.g., Leyequién et al. 2010; Sodhi et al. 2011; Boesing et al. 2017; Prevedello et al. 2018). Thus, landscape structure was calculated using two scales of circular concentric buffers of 600 and 1000 m, both centralized in the middle of the line transect of each bird survey plot. We started with 600 m because smaller buffer sizes did not sufficiently represent the landscape structure variation between the bird survey plots, which did not allow a proper landscape analysis (Fig. 1C, D). Also, we assumed that 1000 meter radius covers all environmental features that could be perceived by the largest number of birds that occur in both investigated crops (e.g., Uezu et al. 2008; Boscolo and Metzger 2009; Marini 2010; Boesing et al. 2017).

Using Fragstat 4.2, we calculated landscape structures that describe the environmental features that could facilitate movement of birds with distinct behaviors and habit preferences through the agricultural landscape. These were: Effective Mesh Size of pasture, sugarcane and native forest (i.e., this metric represents the distribution and size of each land use); Shannon´s Diversity Index (i.e., this metric represents the landscape heterogeneity); and Contagion Index promoted by scattered trees (i.e., metric that represent the permeability of the agricultural landscape. Thus, hereafter all mention of 'permeability' is about this index). See Suppl. material 1B for details of each metric.

Table 1. Land use classes identified through aerial imagery of each focal landscape (Corumbataí River Basin, state of São Paulo, Brazil) and a brief description of each one. The first twelve classes were identified from a CBERS image, while scattered trees were identified using an extra high resolution aerial image (1:25.000 scale). These classes were used to build our land use map from which we obtained our landscape metrics (see Suppl. material 1B).

Land use class	Description
Sugarcane	Annual crop with high biomass accumulation. Comprises the sugarcane matrix
Pasture	Fields composed of tropical grasses. Comprises the pasture matrix
Native forest	Composed of primary and secondary forest
Young-regenerating native forests	Abandoned pasture with shrub and herbaceous vegetation
Forestry	Mainly composed of *Eucalyptus* plantations
Abandoned forestry	*Eucalyptus* plantations with recovered native vegetation understory
Rural buildings	Farmhouse and rural facilities as barns, stables, warehouses etc.
Bare soil	Any terrain without vegetation that was not used for crops during the bird survey
Citriculture	Mainly composed of orange plantations
Watercourse	Rivers, streams, lakes
Urban area	Areas with urban elements (i.e., buildings, streets) recognized
Others	Any other land-use not identified as above
Scattered trees	Any tree found outside of native forest, and 'non-matrix land use type'

Data analysis

We used rarefaction curves for each bird survey plots to calculate the increase in species richness throughout the samples (e.g., Buechley et al. 2015). We also used the estimated number of species through a non-parametric Bootstrap to evaluate the sample effort efficiency. EstimateS 9.1.0 was used for these analyses using 100 randomizations of the presence-absence data obtained from the point counts.

We classified each bird species based on ecological characteristics, including usual habitat of occurrence (i.e., F – forest, NF – non-forest, F-NF – species able to occur in forest and non-forest habits, A – aquatic, F-A – forest and aquatic, NF-A – non-forest and aquatic, and A-F-NF - aquatic, forest and non-forest) and foraging guild (i.e., insectivores, omnivores, granivores, frugivores, carnivores, nectarives, piscivores, scavengers and herbivores), following criteria used in Alexandrino et al. (2013, 2016, 2017). We also identified Atlantic Forest and *Cerrado* endemics (Bencke et al. 2006) and threat status from the state of São Paulo Red List, which follows IUCN criteria (São Paulo 2018). As the first comparative study of these crops in Brazil, we focused our subsequent landscape relationship analyses on the bird trophic guilds and usual habitat of occurrence that have been most reported in agricultural landscapes (e.g., Manhães and Loures-Ribeiro 2005; Alexandrino et al. 2013, 2017) and in scattered trees in rural landscapes (Machado and Rosa 2005; Pizo and Santos 2011). Thus, besides using the total species richness in the assemblages, we chose four foraging guilds (i.e., insectivores, omnivores, granivores and frugivores), as well as three usual habitat of occurrence (i.e., forest species, non-forest species and spe-

cies able to occur in both habitats) to be the dependent variables in our analysis. We followed Piacentini et al. (2015) for bird nomenclature and taxonomy.

We checked assemblage composition similarity between each bird survey plot using cluster analysis and the average linkage method (Manly 2008). Similarity between pasture and sugarcane matrix was checked with the Jaccard similarity index. Both analyses were run at SAS 9.2 using presence-absence data.

We used non-metric multidimensional scaling (NMDS) (Manly 2008) to visualize the relationship between dependent variables and the environmental features in each bird survey plot, using a graphical representation of survey plots as a function of species (e.g., Silva et al. 2015). This analysis was performed using the Bray-Curtis similarity index and the relative abundance data (i.e., PAI) of all species recorded in survey plots.

We also used generalized linear models (McCullagh and Nelder 1989) to check which environmental features exert significant influence on species occurring in both matrices. We used species richness and relative abundance (i.e., PAI) of each bird ecological group as dependent variables. Since our main objective was not test pasture and sugarcane per se versus bird assemblages, as independent variables we used only those landscape features that are dependent on each landscape scheme and management adopted in each crop: we used 'effective mesh size of native forest' (i.e., representing distribution and proportion of area occupied by native forest), 'Shannon´s landscape diversity' and 'matrix permeability exerted by scattered trees' (see Suppl. material 1B for full variable description), and the different interactions between them (Table 2). We highlight that only non-correlated variables (i.e., checked through Pearson's correlation) and variable from a same scale were used in each tested model. Once our studied matrices are strong managed, we also assumed that scattered trees and the amount of forest patches did not have any biological correlation with each other, and the trees' presence was a random result of human management. We used the Akaike Information Criterion (AIC) adjusted for small samples (AICc) for the selection of the best models. We compared each model from each ecological group with their respective null models, which considered a constant PAI or species richness value. We considered acceptable those models with AIC values lower than their null and ΔAIC less than 2. All analyses were run in R (R Core team 2015) and the vegan package was used for NMDS analysis (Oksanen 2015).

Results

Bird species

We identified 137 bird species of 44 families in our bird survey plots, based on 3,501 individual contacts (single birds or groups). We observed 132 bird species in pastures, and 72 species in sugarcane fields. Similarly, we had 2,522 contacts in pasture and 967 in sugarcane. All survey plots in pasture had species richness values

Table 2. Generalized linear models tested for assemblage richness and each bird ecological groups (dependent variables), obtained in eight bird survey plots in sugarcane and cattle pastures matrices (see methods). Each dependent variable was run in function of each model listed. [1] PAI – Punctual Abundance Index, it is a measurement of relative abundance (Vielliard et al. 2010). [2]Shdi – Shannon's diversity index; Sca.trees - permeability exerted by scattered trees (i.e., Contagion Index, see methods); Forest - effective mesh size of native forest; 600 m – Landscape feature obtained in 600 m buffer from the bird survey plot. 1000 m - Landscape feature obtained in 1000 m buffer from the bird survey plot.

Dependent variables[1]		Model [2]
- Assemblage species richness		Shdi 600 m
- PAI of Forest species		Sca.trees 600 m
- PAI of Non-forest species		Forest 600 m
- PAI of Forest/ non-forest species		Pasture 600 m
- PAI of Insectivorous		Sugarcane 600 m
- PAI of Omnivorous		Shdi 600 m+ Sca.trees 600 m
- PAI of Granivorous		Shdi 600 m+ Forest 600 m
- PAI of Frugivorous		Sca.trees 600 m+ Forest 600 m
	In function of:	Shdi 600 m+ Sca.trees 600 m+Forest 600 m
		Shdi 1000 m
		Sca.trees 1000 m
		Forest 1000 m
		Pasture 1000 m
		Sugarcane 1000 m
		Shdi 1000 m+ Sca.trees 1000 m
		Shdi 1000 m+ Forest 1000 m
		Sca.trees 1000 m+ Forest 1000 m
		Shdi 1000 m+Sca.trees 1000 m+Forest 1000 m

higher than those in sugarcane (Fig. 2), a pattern observed throughout the study (see Suppl. material 1C for rarefaction curves). Our sampling effort detected from 84.6% to 90.7% of the total estimated bird species richness in our survey plots of both crops, as indicated by the species richness bootstrap estimator (Fig. 2). The richness and Punctual Abundance Index (PAI) of all bird ecological groups was also higher in pasture, with the exception of granivores, which had similar PAI in both matrices (Fig. 3). The different matrices shared 48% of species composition (Jaccard similarity), and, as expected, bird survey plots within the same matrix type were more similar to each other (Fig. 2).

Although non-forest species were the most observed group (45 species, representing 32.1% of total), forest species (28 species, 20.4% of the total) and species able to occur in both forest and non-forest habitats (33 species, 24% of total) also contributed significantly to the species richness in both crops. Species favoring other habitats accounted for 22.6% of observed species (i.e., aquatic = 15 species, non-forest-aquatic = 10 species, forest-aquatic = 6 species) (Fig. 3, see Suppl. material 1D).

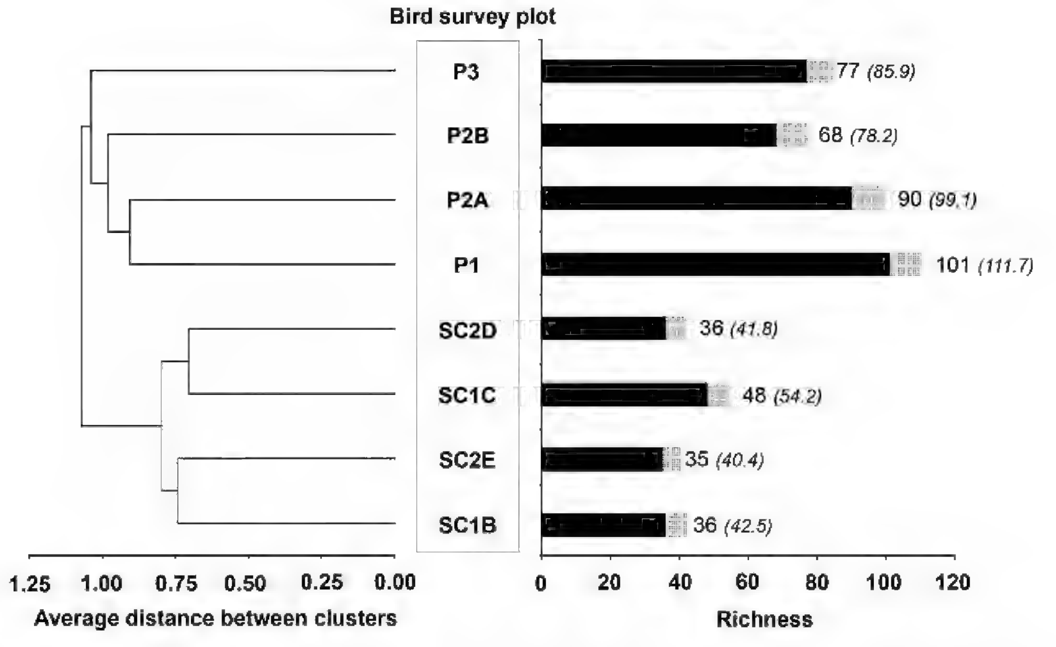

Figure 2. Cluster analysis based on the bird composition observed in eight bird survey plots (left dendrogram) in sugarcane and cattle pastures. Closest branches on dendrogram are more similar. Species richness observed in each bird survey plot is in black bars and value in regular text (right graph). Richness estimation by bootstrap is represented by dashed bars and values in italic. SC means sugarcane matrix, and P means pasture matrix.

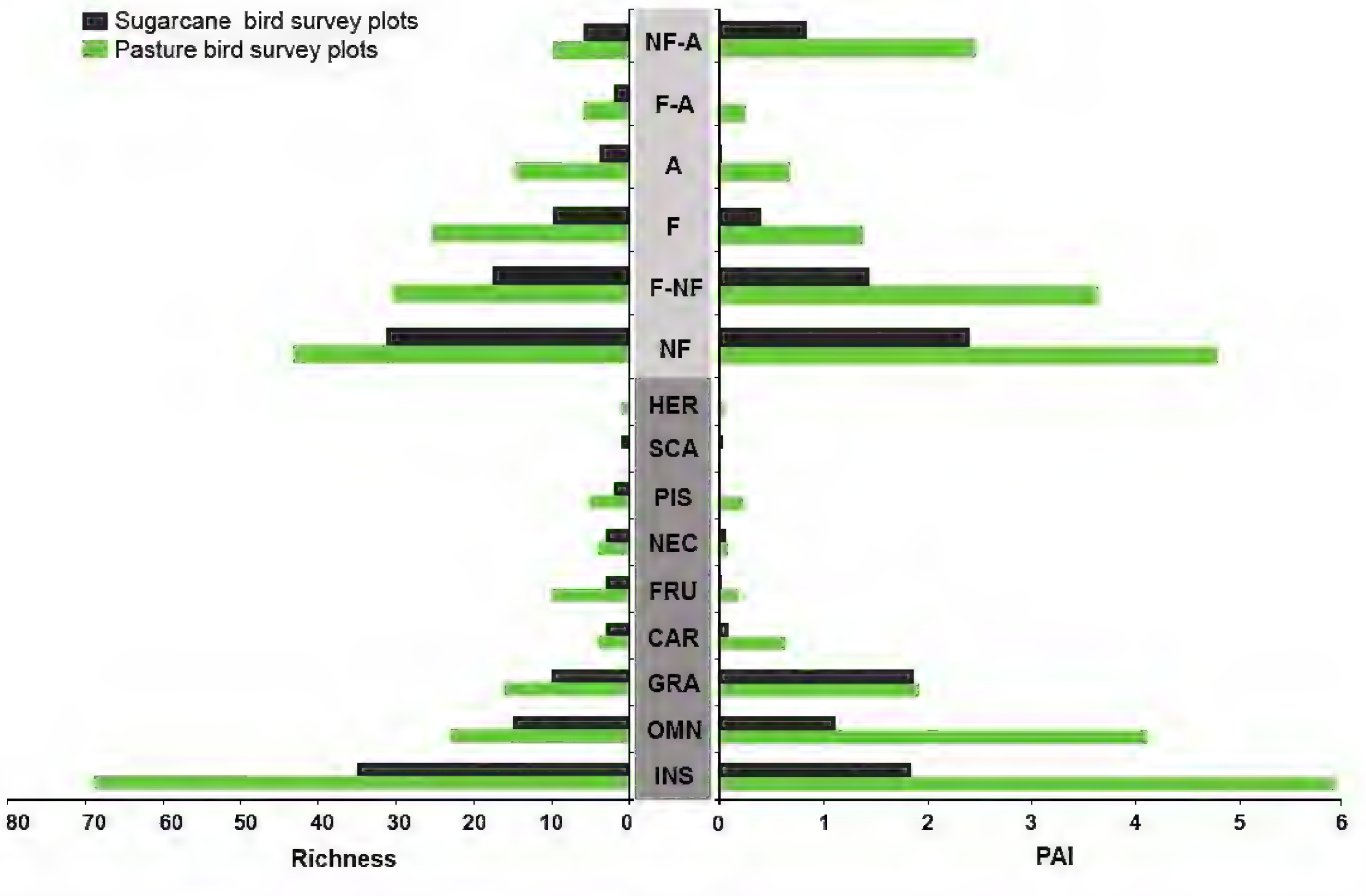

Figure 3. Observed species richness (left figure) and relative abundance through Punctual Abundance Index – PAI (right figure) of species belonging to each usual habitat of occurrence (light gray) and foraging guild (dark gray) in sugarcane and pasture bird survey plots. Abbreviations following the top-down order of appearance in the figure: NF-A – species able to occur in non-forest and aquatic habitat, F-A – species able to occur in forest and aquatic habitats, A – aquatic, F – forest, F-NF – species able to occur in forest and non-forest habitats, NF – non-forest; HER – herbivorous, SCA - scavengers, PIS - piscivorous, NEC - nectarivous, FRU – frugivorous, CAR - carnivorous, GRA - granivorous, OMN -omnivores, INS – insectivorous.

Insectivores, omnivores and granivores were the foraging guilds most observed (Fig. 3). Only three Atlantic Forest endemics (i.e., *Campephilus robustus*, *Tachyphonus coronatus*, and *Todirostrum poliocephalum*) and two *Cerrado* endemics (i.e., *Cyanocorax cristatellus* and *Gubernetes yetapa*) were observed in both crops, with the exception of *T. coronatus*, which was absent from pastures. Four 'near threatened' species for State of São Paulo (i.e., *Amazona aestiva*, *Campephilus robustus*, *Mycteria americana* and *Synallaxis albescens*) were observed only in pasture. The complete species list is provided in Suppl. material 1D.

Landscape structures

More than 63% of the variability in environmental features was explained by two main dimensions: dimension 1 represents landscape composition and the spatial distribution of patches and scattered trees, and dimension 2 represents landscape diversity (Table 3). The NMDS analysis was reliable (Stress = 0.032; parameter that measures the representation efficiency of the obtained dimensions, lower values are more reliable, see Manly 2008). Each landscape structure collected from the 600 m scale showed high positive correlation with the corresponding value collected at the 1000 m scale (e.g., Shdi at 600 m radius was highly correlated with Shdi at 1000 m) (Table 3, Fig. 4a, see Suppl. material 1E). This result demonstrates that the studied sites have the same proportion of land use at both scales of analysis. The Effective Mesh Size of pasture and sugarcane at both scales were negatively correlated (Suppl. material 1E). This result was expected because these metrics define the matrix type found in the bird survey plots of both crops.

Table 3. Proportion of variance represented by two final dimensions obtained by non-metric multidimensional scaling (NMDS) of bird assemblages of sugarcane and cattle pastures. Landscape metrics values are the coordinates used in the NMDS graph. Fitting – values of fitting on NMDS.

	Dimensions			
Variance represented (r^2):	**I**	**II**		
Increment	0.375	0.260		
Cumulative	0.375	0.636		
Variables coordinates and correlation with NMDS axis:			**Fitting**	
			r^2	***P***
Landscape diversity at 600 m (Shdi 600 m)	0.245	-0.969	0.090	0.783
Landscape diversity at 1000 m (Shdi 1000 m)	0.263	-0.964	0.214	0.551
Effective mesh size of pasture at 600 m (Pasture 600 m)	0.996	-0.084	0.753	0.095
Effective mesh size of pasture at 1000 m (Pasture 1000 m)	0.999	0.022	0.584	0.096
Effective mesh size of native forest at 600 m (Forest 600 m)	-0.992	-0.124	0.075	0.813
Effective mesh size of native forest at 1000 m (Forest 1000 m)	-0.997	-0.070	0.188	0.572
Effective mesh size of sugarcane at 600 m (Sugarcane 600 m)	-0.993	0.115	0.663	0.085
Effective mesh size of sugarcane at 1000 m (Sugarcane 1000 m)	-0.987	0.160	0.470	0.21
Permeability exerted by scattered trees at 600 m (Sca.trees 600 m)	0.980	-0.195	0.540	0.142
Permeability exerted by scattered trees at 1000 m (Sca.trees 1000 m)	0.990	0.139	0.639	0.083

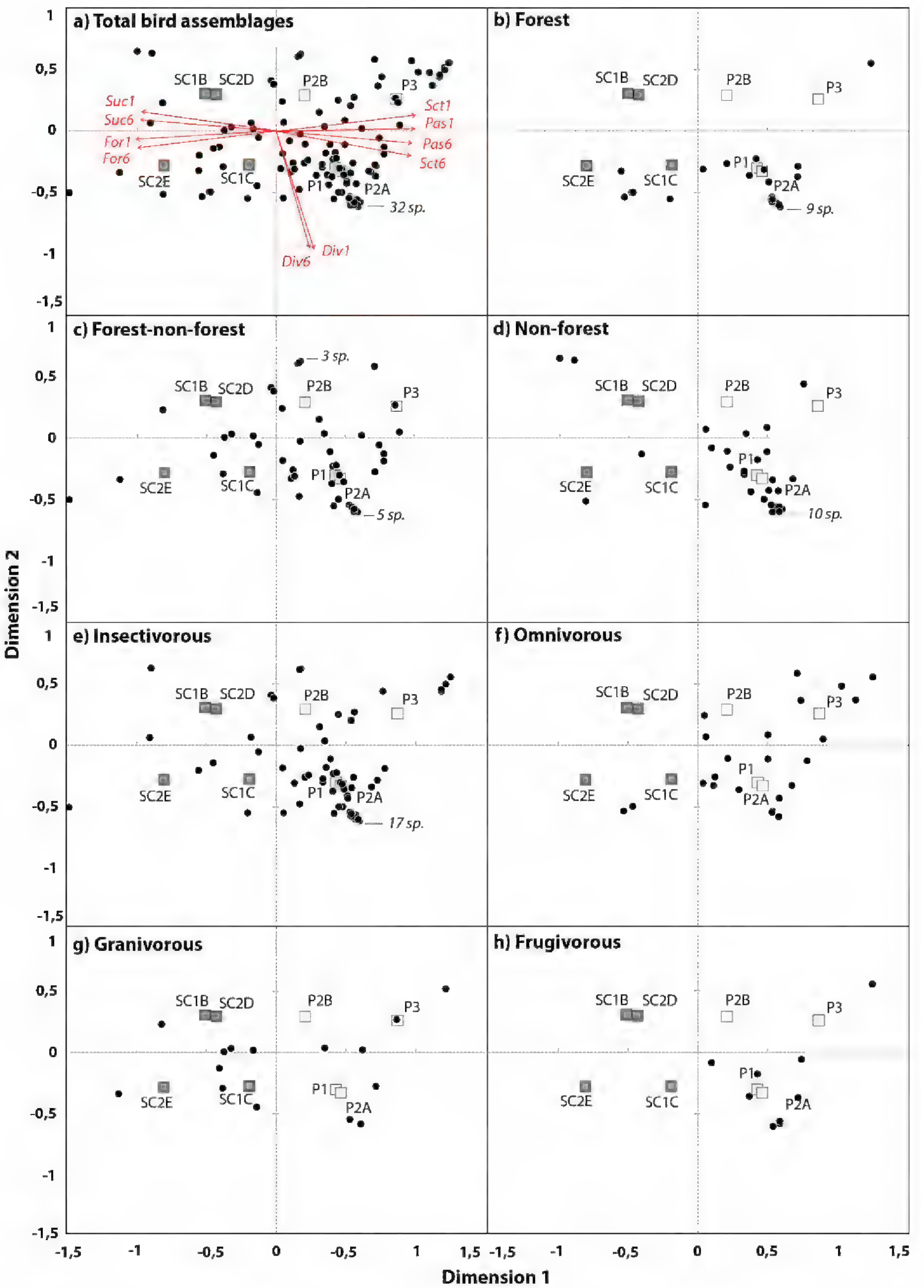

Figure 4. Non-metric multidimensional scaling representing the ordination of the bird survey plots (squares) as a function of the abundances of each species observed in bird assemblages of sugarcane and cattle pastures (black dots) (stress=0.032). Dark gray squares are survey plots in pasture and light gray squares are sugarcane plots. The initials next to the squares are the survey plot name. Environmental features are represented in red arrows: Div1 – Landscape diversity at 1000 m radius; Div 6 - Landscape diversity at 600 m radius, Sct1 - Permeability exerted by scattered trees at 1000 m, Sct6 - Permeability exerted by scattered trees at 600 m, For1 - Effective mesh size of native forest at 1000 m, For6 - Effective mesh size of native forest at 600 m, Suc1 - Effective mesh size of sugarcane at 1000 m, Suc6 - Effective mesh size of sugarcane at 600 m, Pas1-Effective mesh size of pasture at 1000 m, Pas6 - Effective mesh size of pasture at 600 m; Sct1 - permeability exerted by scattered trees at 1000 m, Sct6 - permeability exerted by scattered trees at 600 m. The graphs "b" to "h" highlight the species in the NMDS graph "a", but in ecological groups. Forest-non-forest means species able to occur in forest and non-forest habitats. The overlapped black dots are followed by a short description of how many species are in the same multidimensional space.

All sugarcane surveys plots have higher proportions of sugarcane and forest, but there were plots with low landscape diversity (i.e., SC1B and SC2D) and a more landscape diversity (i.e., SC2E and SC1C, see y-axis in Fig. 4a). All pasture survey plots showed high landscape permeability from scattered trees and a high proportion of pasture, although there were also plots with lower landscape diversity (P2B and P3) (Fig. 4a). In general, we noticed that SC1B and SC2D plots were the most homogeneous landscapes surveyed while and P1 and P2A plots were the most heterogeneous (see Suppl. material 1F for complete results of each landscape metric obtained on each bird survey plot).

Birds vs. landscape structures

We found valid models (ΔAIC < 2) for the following dependent variables: assemblage richness, relative abundance of species able to occur in both habitats (i.e., forest-non-forest species), relative abundance of frugivores, and relative abundance of omnivores. We can assume that the variations of these dependent variables were explained by the variation of the tested landscape structures (Table 4). In contrast, the tested models for non-forest species, forest species, insectivores and granivores were similar to their respective null models, and we cannot conclude that these species have a significant relationship with the tested landscape structures (Table 4).

The assemblage richness variation in the bird survey plots, as well as the relative abundance variation of frugivores, were both better explained by the matrix permeability exerted by scattered trees around the plots (i.e. 600 m radius). At the larger scale (i.e., 1000 m), the landscape diversity and native forest amount have the most influence on the assemblage richness and frugivore abundance in the plots. In contrast, species able to occur in both habitats (i.e., forest-non-forest species) have their relative abundance better explained by the landscape diversity and native forest amount at the larger (1000 m) scale, while permeability exerted by scattered trees was important at the smaller (600 m) scale. For omnivores, the model that included scattered trees at the large scale was the best at explaining omnivores' relative abundance variation (Table 4, see Suppl. material 2).

Using bird assemblage data, the NMDS analysis resulted in a complete separation of sugarcane and pasture (Fig. 4). NMDS illustrates a higher occurrence of birds (i.e., black dots in the graph) in the pasture plots (Fig. 4a). It also illustrates the high occurrence of frugivores in a particular region in the multidimensional space (i.e., near P1 and P2A, see Fig. 4h), which reinforces the frugivore relationship with the environmental metrics tested in the models (scattered trees, landscape diversity and forest, see Table 4).

Although some of our ecological groups did not have consistent models, the NMDS graph indicated that forest species occurred most often in regions with many scattered trees and high landscape diversity, as in bird survey plots in pasture matrix (i.e., P1 and P2A), and least in areas with high levels of forest cover, as in bird survey plots in sugarcane matrix (i.e., SC2E and SC1C, see Fig. 4b). NMDS

Table 4. Plausible models obtained for assemblage richness and each bird ecological groups (dependent variables) obtained in eight bird survey plots in sugarcane and cattle pastures matrices (see methods). See results obtained for all tested models in Suppl. material 2. [1]Shdi – Shannon's diversity index; Sca.trees - permeability exerted by scattered trees (i.e., Contagion Index, see methods); Forest - effective mesh size of native forest; 600 m – Landscape feature collated in 600 m buffer from the bird survey plot. 1000 m - Landscape feature collated in 1000 m buffer from the bird survey plot. [2]Akaike Information Criterion with small samples correction. [3] Difference between AICc of the model and the lowest AICc model (i.e., best model).[4] Akaike weight.

Dependent variables	Model [1]	AICc [2]	ΔAIC [3]	w [4]
Assemblage species richness	Sca.trees 600 m	77.39	0.00	0.50
	Shdi 1000 + Forest 1000 m	78.92	1.53	0.23
Relative abundance (PAI) of:				
Non-forest species	Null	47.98	0.00	0.51
	Sca.trees 1000 m	49.29	1.31	0.27
	Sca.trees 600 m	49.68	1.70	0.22
Forest/ non-forest species	Shdi 1000 + Forest 1000 m	44.20	0.00	0.56
	Sca.trees 600 m	45.87	1.67	0.24
Forest species	Shdi 1000	36.16	0.00	0.36
	Shdi 600	36.59	0.43	0.29
	Null	36.89	0.73	0.25
Insectivorous	Null	51.83	0.00	0.57
Frugivorous	Sca.trees 600 m	21.96	0.00	0.52
	Shdi 1000 + Forest 1000 m	22.89	0.93	0.33
Omnivorous	Sca.trees 1000 m	46.48	0.00	0.78
Granivorous	Null	33.26	0.00	1.00

also helped us to understand the lack of plausible models for granivores. Because this group had similar occurrence values in both matrices (Fig. 4g), they were also dispersed in different parts of the multidimensional space. However, our analysis did not provide an explanation of the relationships of non-forest and insectivorous species to the landscape structure.

Discussion

Birds vs. landscape structures

Species richness patterns in the bird assemblages herein studied were explained by the landscape features of the pasture and sugarcane plots. Our results confirm that heterogeneous agricultural landscapes promote the occurrence of a higher variety of species representing different ecological functions (e.g., Petit et al. 1999; Benton et al. 2003; Petit and Petit 2003; Bennett et al. 2006; Fahrig et al. 2011). Furthermore, we observed about twice the bird species richness and a higher relative abundance in pasture plots. Such plots also have twice as many forest species than sugarcane and some threatened species were recorded in pasture plots. Thus, the different

composition of species with different ecological habits and conservation status reinforces that these landscapes have highly disparate assemblages and biological value.

Higher occurrence of forest species (i.e., F, F-A, F-NF species) in pasture was also observed in Petit and Petit (2003). However, we also recorded some of these species in sugarcane (e.g., *Elaenia flavogaster*, *Brotogeris chiriri*, *Synallaxis frontalis*, *Crypturellus tataupa* and *T. coronatus*). Although forest species and 'forest-non-forest species' were not associated with any landscape feature, the NMDS results indicated that they have a preference for high landscape diversity and more permeable landscapes with more scattered trees instead of more forest habitats nearby (Fig. 4). Landscape diversity has been shown to be an important factor to facilitate forest bird occurrence in agricultural landscapes (e.g., Ferraz et al. 2012), and also to promote forest bird species richness (e.g., Petit and Petit 2003; Bennett et al. 2006). Scattered trees promote higher heterogeneity and act as stepping-stones for forest species moving through agricultural landscapes (e.g., Fischer and Lindenmayer 2002; Uezu et al. 2008; Fahrig et al. 2011; Prevedello et al. 2018; Vogel et al. 2018). Boesing et al. (2017) observed that in pasture with low heterogeneity (i.e., with few scattered trees) the occurrence of forest-dependent birds were lower in comparison to permeable coffee plantations. Thus, this is an evidence that in an agricultural landscape the matrix quality (i.e., in terms of environmental features that allow bird movement through the matrix) seems to be of similar importance for forest bird occurrence inside a crop as the amount of forest patches within the landscape (Benton et al. 2003; Kupfer et al. 2006; Driscoll et al. 2013; Biz et al. 2017; Prevedello et al. 2018).

The prevalence of insectivorous, omnivorous and granivorous species in our survey plots resembles their occurrence pattern observed in other tropical anthropogenic landscapes (e.g., Petit et al. 1999; Anjos 2004; Tejeda-Cruz and Sutherland 2004; Manhães and Loures-Ribeiro 2005; Alexandrino et al. 2013, 2017; Vitorino et al. 2018). Although we did not find a clear relationship of insectivores and granivores with the landscape structures, these guilds have been reported using scattered trees in other southeastern Brazilian pastures (Machado and Rosa 2005; Pizo 2007; Pizo and Santos 2011). Some of these species may use them as stepping stones in their movement across agricultural landscapes (e.g., Uezu et al. 2008), perch sites for foraging behavior (Sick 1997; see Pizo and Santos 2011), or even consuming zoochorous fruits of scattered trees (Machado and Rosa 2005, Pizo 2007). The relationship of omnivores and frugivores to scattered trees may be related to their seed dispersal behavior through agricultural matrices, and also to the attractiveness of isolated fruiting trees for these birds (Machado and Rosa 2005; Pizo and Santos 2011; Silveira et al. 2016). In a previous study, Carreira (2013) reported seeds of zoochorous species under scattered trees next to our pasture plots, all with appropriate size to be dispersed by local omnivorous and frugivorous birds (Pizo 2007; Bello et al. 2017). Thus, our results corroborate Carreira's (2013) findings. In addition, the relationship of frugivores with native forest cover at larger scales (1000 m) is an indication that their occurrence in agricultural crops is also dependent on the forest

patches nearby (Uezu et al. 2008). We believe that forest cover and landscape diversity are factors related to food provisioning for these birds in agricultural landscapes (Fischer and Lindenmayer 2002; Machado and Rosa 2005; Pizo and Santos 2011), which promotes their movements through landscapes (Uezu et al. 2008; Prevedello et al. 2018). With respect to granivores, Petit et al. (1999) also reported similar species richness values between pasture and sugarcane. Granivores do well in tropical open agricultural landscapes (Sekercioglu 2012; Vitorino et al. 2018) and this guild seems able to use sugarcane and pasture landscapes equally well in our region.

Implications for bird conservation in agricultural landscape

Our research contributes to two aspects of bird conservation in agricultural landscapes. Firstly, these results contribute to the debate on how best to balance agricultural production and maintenance of biodiversity. In recent decades two concepts have emerged: 'land sparing' and 'land sharing'. Land sparing advocates propose crop intensification in high yield in extended areas, while sparing relatively large tracts of land for biodiversity conservation (e.g., large and aggregated reserves of natural habitat) (see Phalan et al. 2011, 2016). Land sharing advocates propose a landscape with a variety of crops in a non-intensive fashion, with scattered, relatively smaller reserves of natural habitats nearby (see Fischer et al. 2008, 2011). Decisions to apply land sharing or land sparing models over the agricultural landscapes are also dependent on the socio-economic factors and crop production characteristics (e.g., Phalan et al. 2011, 2016). Although we did not evaluate the yield provided by the sugarcane and pasture, or local socio-economic subjects, according to our landscape structure measurements and the management adopted on each crop, the sugarcane fields were similar to a land sparing model, while pastures in small family farms were similar to a land sharing model. Albeit we observed a higher amount of native forest in the sugarcane landscape, it was not sufficient to support the occurrence of a higher number of forest specialist bird species, nor a variety of foraging guilds inside this crop. In the same focal landscapes, Alexandrino et al. (2016, 2017) found bird richness and composition to be very similar between forest patches in pastures and sugarcane, indicating that forest patches of both matrices have similar importance for regional bird diversity. However, in Brazil, rural properties follow as an environmental compensation model based on federal law that requires that a certain amount of forest cover is retained (Brazil 2012), but this law does not specify the quality of the forest. Hence, many forest patches in agricultural landscapes of southeast Brazil are degraded (e.g., Vidal et al. 2016), as is the case in our study area (Ferraz et al. 2014; but see Alexandrino et al. 2017). Thus, all these facts led us to conclude that, in the regional context of our study, small native forest patches are insufficient to promote regional biodiversity by themselves (Ferraz et al. 2014; Verdade et al. 2014), and we cannot expect that only sparing these forest patch reserves will be sufficient to conserve regional bird communities. Since we found high heterogeneity of habitats promoting higher bird richness and assemblages with more

diverse ecological functions, we argue in favor of agricultural landscapes with these characteristics, instead of homogeneous schemes.

Although our studied landscapes have not experienced significant changes in the amount of sugarcane and pastures throughout the years (Ferraz et al. 2014), sugarcane expansion in other agricultural landscapes has been observed in recent years (Rudorff et al. 2010; Lourenzani and Caldas 2014), encroaching on natural habitats (Bernard et al. 2011; Verdade et al. 2012). One of the reasons is the recent increase in international demand for biofuel to substitute fossil fuels (e.g., Webb and Coates 2012), and ethanol from sugarcane has been defended as highly beneficial for human wellbeing in comparison to other crops for biofuel production (i.e., important for reduction in greenhouse gas emissions, see Figueiredo et al. 2010; good costs-effectiveness, see Jonker et al. 2015). Thus, it is expected that new sugarcane crops will replace other Brazilian crops, such as pastures (Leite et al. 2009). Bearing in mind that current management and environmental characteristics of sugarcane do not comprise a wildlife-friendly scheme, we predict that sugarcane expansion to other heterogeneous agricultural landscapes will have a drastic negative impact on bird diversity, as long as the sugarcane sector keeps applying a homogeneous scheme. Therefore, we also recommend updates in environmental laws and policies associated with sugarcane production to promote habitat heterogeneity and landscape diversity in this crop.

The second contribution of our findings goes in filling the knowledge gap regarding which species may occur in pasture and sugarcane matrices, which is useful for landscape ecologists. Bird usage of anthropogenic landscapes is extremely complex. Some birds require vital resources (i.e., food supply, water source, substrate and viable territory for nesting) that are found in different land use types and structural elements that are present in anthropogenic landscapes (e.g., Fischer and Lindenmayer 2002; Pizo and Santos 2011). We highlight that 28% of forest specialist species and 84% of species able to occur in forest and non-forest habitats (i.e., forest-non-forest), which were observed in small forest patches in our focal landscapes (see Alexandrino et al. 2016, 2017), were also observed in the agricultural habitats surveyed. Therefore, our results corroborate that the concept of "habitat surrounded by non-habitat matrix", which is based on the theory of island biogeography, may be flawed (Kupfer et al. 2006; Driscoll et al. 2013). When this concept is implicitly followed, ecological research and conservation assessment of forest patches in agricultural landscapes may be compromised (Kupfer et al. 2006; Fahrig et al. 2011).

As a final message, bird conservation concern is not focused only on current threatened species, but it should ensure that common species today will stay common in the future (Sodhi et al. 2011). There is a global concern in establishing wildlife-friendly farm schemes (Fischer et al. 2008; Fahrig et al. 2011). Countries with agricultural sectors similar to those in Brazil should consider agricultural landscapes as essential for wildlife conservation. Otherwise, biodiversity impoverishment in many agricultural landscapes is to be expected, as well as the efforts for conservation are to be hindered in these landscapes.

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Supplementary material 1

Procedures used for the land use map building; details about the landscapes variables; rarefaction curves; Pearson´s correlation; full sampled species list

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Data type: methodology

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Supplementary material 2

Sequence of GLM run and model selection

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Data type: statistical data

Explanation note: Species appearance follows alphabetic order.

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